

RUGGEDIZED FIBER OPTIC SOUND VELOCITY PROFILER

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT ANTHONY A. RUFFA, citizen of the United States of America, employee of the United States Government, a resident of Hope Valley, County of Washington, State of Rhode Island, has invented certain new and useful improvements entitled as set forth above of which the following is a specification.

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3 **RUGGEDIZED FIBER OPTIC SOUND VELOCITY PROFILER**

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5 **STATEMENT OF GOVERNMENT INTEREST**

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 governmental purposes without the payment of any royalties
9 thereon or therefore.

10

11 **BACKGROUND OF THE INVENTION**

12 (1) Field of the Invention

13 The present invention relates generally to a system for
14 establishing the sound velocity profile of a medium, and more
15 particularly to a cable for use in such a system.

16

17 (2) Description of the Prior Art

18 Undersea cables containing optical fibers are well known in
19 the art. U.S. Patent No. 5,125,062 to Marlier et al. relates to
20 an undersea telecommunications cable having optical fibers. The
21 undersea cable has an optical fiber embedded in material filling
22 a tube which itself lies inside a helical lay of metal wires
23 having high mechanical strength, the interstices between the
24 wires of the helical lay being filled with a sealing material.

1 The helical lay is surrounded by an extruded sheath made of an
2 electrically insulating and abrasion resistant material, and for
3 the purposes of remotely powering equipment interposed on the
4 cable, the cable includes conductive means either belonging to
5 the helical lay or surrounding it, which conductor means is
6 surrounded by the sheath.

7 U.S. Patent No. 4,971,420 to Smith relates to an optical
8 fiber cable for submarine use which has a core surrounded by a
9 layer of strength members which include both wires and laser
10 welded metallic tubes containing the optical fibers.

11 U.S. Patent No. 5,212,755 to Holmberg relates to an armored
12 fiber optic cable having both fiber optics and armor wires
13 located outside the cable core in position where the fiber
14 optics experience low strain when the cable is under stress. In
15 one embodiment, metal armor wires and optical fibers embedded in
16 metal tubes are arrayed in one or more layers about and outside
17 the cable core. In another embodiment, KEVLAR armor wires and
18 optical fibers embedded within a hard composite shell are
19 arrayed in one or more layers about and outside the cable core,
20 and a layer of KEVLAR armor is provided surrounding the one or
21 more layers. In each of the embodiments, the strains that the
22 fiber optics experience due to core stresses and due to core
23 residual strain is materially reduced over other armored fiber
24 optic cables.

1 U.S. Patent No. 5,495,547 to Rafie et al. is directed to a
2 well logging cable including first conductor elements, each of
3 the first elements consisting of a steel wire surrounded by
4 copper strands and covered in an electrically insulating
5 material, and at least one second conductor element including at
6 least one optical fiber enclosed in a metal tube, copper strands
7 surrounding the tube and strands covered by the electrically
8 insulating material. The first elements and the at least one
9 second element are arranged in a central bundle. The second
10 conductor element is positioned within the bundle so as to be
11 helically wound around a central axis of the bundle. The bundle
12 is surrounded by armor wires helically wound externally to the
13 bundle.

14 The velocity of sound through a medium depends upon a
15 number of factors including temperature, pressure and density.
16 In the case where the medium is seawater, sound velocity also
17 depends on the salinity of the seawater. In many situations, it
18 is necessary to obtain accurate measurements of sound velocity
19 through a medium along an axis, such as obtaining a profile of
20 sound velocity of a water column. For example, sound velocity
21 measurements or profiles are needed for accurate sonar location
22 of objects on the sea bottom in recovery operations or for
23 accurate bottom mapping.

1 U.S. Patent No. 5,734,623 to Ruffa illustrates a fiber
2 optic cable, coated to increase its sensitivity to acoustic
3 pressure, which may be towed through a medium. The optical
4 fiber contains Bragg grating sensors at regular intervals along
5 its length. A steerable array of transducers sends a pulse of
6 sound in the direction of the optical cable while broadband
7 pulses of light are directed down the optical fiber. The pulses
8 of light are selectively reflected back according to the spacing
9 between the Bragg gratings. The sound pressure field causes a
10 local strain in the fiber, thus changing the wavelength of the
11 grating. The sound velocity profile along the length of the
12 optical cable is computed by measuring the amount of time
13 necessary for successive Bragg gratings to respond to the
14 acoustic pressure associated with the advancing wave front of
15 the acoustic pulse.

16 Although an instrumented tow cable that continuously
17 measures the sound velocity profile has the potential to
18 significantly improve sonar performance, it has not yet been
19 realized in fleet sonar systems. One of the main obstacles is
20 to design such a system that is sufficiently rugged to survive
21 deployment and retrieval through handling systems at high speeds
22 which lead to high tensions. This requirement alone rules out
23 attaching devices to the cable or embedding devices into the
24 protective jacket surrounding the cable such as thermistors to

1 measure the temperature profile of the ocean. For this reasons,
2 fiber optic Bragg grating-based sensors are ideal, since they
3 require no wires or preamps that can be crushed; the fiber is
4 the sensor.

5

6 **SUMMARY OF THE INVENTION**

7 Accordingly, it is an object of the present invention to
8 provide an optical fiber cable which is sufficiently rugged to
9 survive deployment and retrieval.

10 It is a further object of the present invention to provide
11 an optical fiber cable which can be used in a fiber optic sound
12 velocity profiler.

13 The foregoing objects are achieved by the optical fiber
14 cable of the present invention.

15 An optical fiber cable in accordance with the present
16 invention broadly comprises at least one inner layer of strength
17 members, an outer layer of strength members, and at least one
18 tube containing at least one optical fiber incorporated into
19 said outer layer.

20 Further, in accordance with the present invention, a system
21 for determining a velocity profile of sound in a medium is
22 provided. The system broadly comprises an optical fiber cable
23 suspended in the medium, the optical fiber cable having at least
24 one inner layer of strength members, an outer layer of strength

1 members, and at least one tube containing at least one optical
2 fiber incorporated into said outer layer, the at least one
3 optical fiber having a plurality of Bragg grating sensors along
4 its length, an optical pulse generator for sending an optical
5 pulse into the optical cable, an acoustic pulse generator for
6 sending an acoustic pulse generally along the length of the
7 optical fiber cable, the acoustic pulse causing local strain in
8 the optical cable, the local strain causing the Bragg grating
9 sensors in the vicinity of the strain to selectively reflect the
10 optical pulse back in the direction of the optical pulse
11 generator, a timer for receiving the reflected optical pulse and
12 measuring a time of arrival of the reflected optical pulse, and
13 a processor for computing the sound velocity profile as a
14 function of the time of arrival.

15 Other details of the ruggedized cable of the present
16 invention, as well as other objects and advantages attendant
17 thereto, are set forth in the following detailed description and
18 the accompanying drawings wherein like reference numerals depict
19 like elements.

20

21 BRIEF DESCRIPTION OF THE DRAWINGS

22 FIG. 1 is a cross sectional view of an optical fiber cable
23 in accordance with the present invention;

1 FIG. 2 is a schematic representation of a sound velocity
2 profiler system; and

3 FIG. 3 is a representation of a portion of the optical
4 fiber cable of FIG. 1.

5
6 **DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

7 FIG. 1 illustrates a ruggedized optical fiber cable 12 for
8 use in a sound velocity profiler system. The cable 12
9 has an inner layer 14 of strength members 15, with each strength
10 member 15 preferably being formed by a plurality of steel wires
11 encased in a plastic tube. The cable 12 further has one or more
12 additional layers 16 of strength members 17 with each strength
13 member 17 preferably formed by a plurality of steel wires
14 encased within a plastic tube. Surrounding the additional
15 layer(s) 16 is a jacket 18 preferably formed from a plastic
16 material such as polyurethane. If desired, each of the layers
17 14 and 16 may be wrapped with a tape-like material which acts as
18 a water block.

19 One or more outer layers 20 of strength members 22 surround
20 the jacket 18. Each of the layers 20 includes a plurality of
21 strength members 22 having an outer diameter. Each strength
22 member 22 may also comprise a plurality of steel wires encased
23 within a plastic tube (e.g., "steel lite" as mentioned below).
24 Incorporated into at least one of the outer layers 20 is at

1 least one tube 24, preferably formed from a stainless steel
2 material. Each tube 24 preferably has an outer diameter
3 identical to the outer diameter of strength members 22.
4 Alternatively, the diameter can be slightly smaller, then built
5 up to the diameter of 22 with a polymer coating. Incorporated
6 into each tube 24 is one or more optical fibers 26. The optical
7 fiber(s) 26 preferably float within a gel material 27. As shown
8 in FIG. 3, a plurality of Bragg grating sensors 126 are
9 incorporated into and regularly spaced along the length of one
10 or more of the optical fiber(s) 26.

11 The outermost outer strength layer 20 is in turn surrounded
12 by a primary outer jacket 30. The jacket 30 may be formed from
13 any suitable material known in the art such as a polyurethane
14 material.

15 If desired, each tube 24 may be placed between adjacent
16 ones of said strength members 22.

17 The optical fiber cable 12 of the present invention may be
18 used in a sound velocity profiler system 100 such as that shown
19 in FIG. 2. An optical fiber cable 12 is towed through a medium
20 114 from a platform 116. A steerable array of transducers 118
21 is attached to platform 116. The array 118 is capable of
22 sending a beam of sound, or acoustic pulse, having a specified
23 frequency and amplitude in a desired direction. Optical source
24 120 is optically connected to cable 12 for sending pulses of

1 light into cable 10. FIG. 2 also illustrates a heavy body 122
2 attached to the end of cable 12 which aids cable 12 in reaching
3 a specified depth. In operation, array 118 sends an acoustic
4 pulse in the direction of cable 12.

5 As shown in FIG. 3, a series of Bragg grating sensors 126,
6 well known in the art, are regularly spaced along the cable 12.
7 The advancing pressure front of the acoustic pulse causes local
8 strain in cable 12, thus changing the grating wavelength. A
9 light pulse from optical source 120 is selectively reflected
10 back along the length of cable 12 according to the local strain
11 in cable 12. The sound velocity in medium 114 is computed by
12 processor 132 as a function of the amount of time necessary for
13 successive grating sensors to respond to the advancing pressure
14 front as measured by timer 134. The time of maximum response
15 for each Bragg grating sensor is recorded and this time is
16 divided by the distance to the Bragg grating sensor to obtain
17 the velocity through the water column to the Bragg grating. The
18 amplitude of the acoustic pulse can be increased as necessary to
19 produce sufficient strain for activating sensors 126.

20 Where broadcasting acoustic noise is a concern, the
21 frequency of the acoustic pulse can be high enough such that it
22 is attenuated at large ranges. In order to direct the acoustic
23 pulse in the direction of cable 12, an estimate of towing angle
24 is needed. The towing angle may be determined using the

1 equation set forth in U.S. Patent No. 5,734,623 which is hereby
2 incorporated by reference herein. While such factors as cable
3 diameter, weight, density, and drag coefficient can be
4 accurately determined, the exact tow speed may not be easily
5 obtained. An estimated speed may be used to calculate an
6 estimated critical angle. The acoustic pulse can then be
7 steered about the estimated critical angle until the response
8 from sensors 126 is maximized at the true towing angle. It is
9 to be noted that in determining the true towing angle in this
10 way, an accurate measure of the tow speed is also provided.

11 The cable described hereinbefore was tested under
12 conditions that simulate Navy handling systems. It was cycled
13 over a sheave for 750 cycles for tensions up to 22,500 lbs. with
14 no detrimental effects to the fibers. This proves the
15 feasibility of incorporating Bragg grating-based sensors on one
16 or more fibers contained in a tube located on the outer strength
17 member layer of a tow cable. This is an improvement over the
18 construction shown in U.S. Patent No. 5,734,623, which involves
19 locating the tube containing fibers in the center of the tow
20 cable. When the fibers are located in the center the received
21 acoustic pulse can be degraded while passing through the
22 acoustically complex cable structure.

23 If desired, the steel wires forming the strength members
24 may be replaced by an armored fiber, one version of which is

1 known commercially as "Steel-Lite", a trademark of the Rochester
2 Corporation. The outer diameter of the Steel-Lite cable would
3 be the same as the outer diameter of the steel armor wire it
4 replaces.

5 It is apparent that there has been provided in accordance
6 with the present invention a ruggedized fiber optic sound
7 velocity profiler which fully satisfies the objects, means, and
8 advantages set forth hereinbefore. While the present invention
9 has been described in the context of specific embodiments
10 thereof, other alternatives, modifications, and variations will
11 become apparent to those skilled in the art having read the
12 foregoing description. Accordingly, it is intended to embrace
13 those alternatives, modifications, and variations as fall within
14 the broad scope of the appended claims.